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A WIDE-BAND ELECTRODYNAMIC VIBROMETER (SEISMOGRAPH) FOR THE AUDIO FREQUENCIES

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Of all the vibrometric equipment described in literature, only two portable instruments are especially designed for operation in the audio-frequency range, namely the electrodynamic vibrometer made by the "Philips" firm and the piezoelectric vibroprobe made by the Shure Brothers firm. However, the range of both instruments is limited to frequencies from about 10-30 cycles to 500-1,000 cycles. Moreover, the present status and the prospects for further development of applied acoustics require that vibrations be measured in a considerably wider frequency band, at least up to 3,000-5,000 cycles; the vibrometer should also have very high sensitivity, which would permit it to measure the amplitudes of vibration having velocities of the order of 10^{-5} - 10^{-6} centimeters per second.

The electrodynamic vibrometer designed by the author and his colleagues satisfies these specifications. It is useful in studies of terrestrial vibrations of buildings, mechanisms, etc., in a wide audio-frequency band. The construction of this instrument is new in this field and is therefore not free from certain defects, which, however, do not interfere with its successful use. Its sensitivity is approximately 1,000 times greater than that of the instruments mentioned above and its frequency band is considerably wider.

One of the real advantages of this instrument is the fact that the transmitting element can be removed considerable distances from the measuring part of the instrument. The vibrometer is portable and insensitive to moisture or temperature variations.

The vibrometer registers the amplitude of the vibrating velocity exciting the surface and is equally suitable for measuring both vertical and horizontal vibrations.

The vibrometer described has a light inertial mass and appreciable, although not very great, internal damping which guarantees good stability of the

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transmitting element on the exciting surface even at considerable accelerations. Externally, it has the form of a rectilinear parallelepiped with dimensions 135 x 135 x 120 millimeters. The casing is made from 12-millimeter aluminum plates screwed together. The plates are painted for hermetic sealing. The hose is brought out through a special sleeve with a collar mounted in one of the sides. A permanent magnet is mounted in the bottom of the casing, and a sound coil, which serves as the inertial mass, is located in the gap of the magnet. The coil weighs 35 grams together with the bronze bushing on which it is wound. Three conical legs for installing the vibrometer in the vertical position on the surface under study are screwed into the bottom of the casing directly beneath the magnet. Three additional legs are placed on one of the lateral surfaces for measurements of horizontal vibrations.

Constant sensitivity in the vibrometer is guaranteed for any spatial orientation. The sound coil has a margin of height for the winding which is sufficient to compensate for the static sag of the inertial mass when the instrument is changed from the horizontal to the vertical position. The amount of sag is determined by the natural frequency of the inertial mass, i.e. by the lower limit of the vibrometer's frequency range. In this case, the sag was 1.5-1.7 millimeters, which corresponds to a natural frequency of 12-13 cycles. Moreover, the margin of height was designed in order to make possible distortion-free measurements of vibrations having quite large amplitudes.

In the audio-frequency range, the amplitude of displacement does not usually exceed 0.2-0.3 millimeter. However, the amplitude of vibrations of the inertial mass at the natural frequency exceeds the value pointed out by 1/G times. In this instrument, damping is about 0.25, while the increase (mechanical) at the natural frequency reaches 3.5-4 times. Therefore, the margin of height of the winding necessary to secure undistorted reproduction of a given amplitude is 2.5-3 millimeters. To satisfy the universality requirement (with respect to spatial orientation) and secure the necessary dynamic range, the total margin of height of the winding should be of the order of 4.5-5 millimeters. In our instrument, the height of the winding was increased to 16 millimeters for a gap height of 8 millimeters, which provides, along with the calculated margins, a slight additional margin (about 3 millimeters) to allow for inaccuracy of adjustment of the coil in the gap and possible overloads on the instrument.

The coil was suspended from two flat Monel metal springs, each 0.15 millimeter thick and 10 millimeters wide. The springs were made about 50 millimeters long in order that the movement of the coil in the gap could be considered with sufficient accuracy to be progressive even for large vibration amplitudes. The length of the springs can be adjusted by moving the strip, in which their ends are fastened, by means of a special bracket on the front flange of the magnet. This bracket is strengthened by an additional support which connects it to the vibrometer case for the purpose of eliminating frequency distortions which arise due to resonance vibrations of the bracket.

Damping in this instrument is electromagnetic. The bronze bushing of the sound coil is the damper in which a current is induced, this current opposing, according to Lenz's Law, its motion in the gap of the magnet. Placing the sound coil and the damping ring in one gap is undoubtedly more advantageous than using a special gap for the damping ring as was done by Severs. Unfortunately, we were unable to bring damping to its optimal value (due to the poor quality of the magnet), and therefore a peak about 5 decibels high at the natural frequency of the inertial mass forms in the over-all frequency response. In connection with this, the damping time of natural vibration is 0.5 second for 100-fold damping and 0.75 second for 1,000-fold damping. Thus the instrument is not suitable for studying rapidly varying processes and sudden pulses.

A portable four-stage amplifier from an audio-pressure meter (Model 5-c) of the Siemens-Halske firm was used as a measuring amplifier for the vibrometer. The frequency response of the amplifier is rectilinear above 200 cycles, while at

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lower frequencies it is comparatively smooth, which is compensated by the rise in the response of the transmitting element. A profiling instrument with a copper-oxide rectifier in a Grätz circuit is connected to the amplifier output. Amplification is regulated in steps of 6-8 decibels with a total regulation ban^d of 80 decibels. The amplifier power supply is placed in a separate case; thi[illegible] e also contains all connecting cables and hoses, auxiliary gear, instruments, etc. The portable octave filter made by the same firm, which is especially designed for band analysis of sound, is also very suitable for analysis of vibrations, especially nonstationary ones when harmonic analysis is practically impossible. The filter is connected between the transmitting element and the amplifier.

In certain cases, additional amplification is necessary to increase the sensitivity of the response. A two-stage microphone amplifier IRPA, having amplification of 45 decibels at frequencies from 100 cycles and up, is used for this purpose. At lower frequencies, the amplification drops sharply, and thus it is impossible to measure vibrations at frequencies below 40-50 cycles with the additional amplifier. On the other hand, there is no necessity for these measurements, since such low-frequency vibrations are usually quite strong. The additional amplifier is connected in front of the filter and is used only for measuring very weak vibrations at high frequencies.

The vibrometer was calibrated with the help of a special electrodynamic calibrating platform. Initially, the instrument's frequency response was very uncertain. It contained a number of peaks and dips due to the natural vibrations of the supporting springs and angle bracket of the forward flange of the magnet.

The afore-mentioned strengthening of the angle bracket of the flange eliminated some of these; secondary resonances of the springs were eliminated or considerably reduced by a spongy rubber cushion beneath their special dampers.

As a result, irregularities in the frequency response were almost completely eliminated, with the exception of a resonance peak at the natural frequency and a dip of about 6 decibels near 600 cycles due to one of the insufficiently damped secondary resonances of the springs. In the remainder of the band up to 5,000 cycles, response irregularities do not exceed plus or minus one decibel.

Without the additional amplifier, the vibrometer measures the speeds of vibration up to one micron per second; and with the additional amplifier, up to 6 millimicrons per second. At a frequency of 10 cycles, this corresponds to displacement of 16 millimicrons (without the additional amplifier) and one angstrom (with the additional amplifier). In practice, the lower limit of the dynamic band of the instrument is always determined by the microseism level (vibrational background). In the low-frequency region of the sound band, microseisms in calm periods are approximately one micron per second; for medium and high frequency, their level may be tens and even hundreds of times lower.

The dynamic band of the vibrometer near the natural frequency is determined by the margin of height of the winding of the sound coil, which assures measurements without notable distortions of speeds up to 2.5-3 centimeters per second. For frequencies far removed from the natural frequency, this limit is increased 3-4 times.

The reaction of the vibrometer when set in the proper position for the measurement of horizontal vibrations, but excited by vertical vibrations, does not exceed one percent of the reaction for the "vertical" position. The transmitting element may be taken as far as 500 meters from the "track" amplifying part when using a line 0.5 square millimeter in cross section. The sensitivity is reduced by 0.5-0.6 decibel and the instrument operates stably for variations in external temperature from -30 degrees to 50 degrees centigrade. Despite its high sensitivity in a wide band of audio frequencies, the vibrometer does not react at all to atmospheric noise, even of very great intensity (110-120 decibels).

G. A. Surin participated in designing the instrument. Valuable advice and instructions were given by N. N. Andreyev, Corresponding Member of the Academy of Sciences USSR, and by Professors S. N. Rzhevkin and L. A. Ryabinkin.

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